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16- CELL BACK-TO-BACK STACKED MULTICELL CONVERTER

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ABSTRACT

This paper purposes the harmonic analysis with a new control topology for Back-To-Back Stacked Multicell Converter (BTBSMC) that generates higher number of output voltage levels with lower number of power electronic switches. The BTBSMC is a topology composed of two conventional SM converters, which are connected back-to-back by two low frequency switches. The control topology used in this paper is depends on sector modulation, identification and reference angle generation. In comparison with the Phase Shifted Pulse Width Modulation (PSPWM), the main advantages of the proposed control topology is not required the shifting of the reference waveform and easy to apply this technique to generate higher number of output voltage levels. This paper also proves that by comparing the results by using four, eight and sixteen cell stacked multicell converters, with increasing the number of output levels THD is decreasing, power quality is improving. The converter used is simulated using MATLAB software and the results are presented to validate the effectiveness of the topology.

KEYWORDS: Back-To-Back Stacked Multicell Converter, Modulated Sector Control, THD, Power Quality

INTRODUCTION

In recent years, multilevel converters are widely used in medium/high voltage power applications. Multilevel converters can be considered a mature and proven technology. These are commercialized products that power a wide range of applications, such as compressors, extruders, pumps, fans, grinding mills, rolling mills etc, [2]. This is because the multilevel converters such as lower harmonic distortion and higher power quality which are obtained by increasing the number of output voltage levels [1]. By increased number of components, the converter output voltage waveform approaches nearly sinusoidal waveform that results in the better harmonic characteristics. Some of the fundamental multilevel topologies include the diode –clamped, flying capacitor, and cascaded H-bridge structures. Recently, with increase in the rating of the available switches. There has been much interest in new topologies aiming to reduce the amount of semi conductor devices [5]. Depending on the switching frequency of multilevel converters, the switching stratagies can be classified into two catagories as high switching frequencies, including carrier based Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Modulation (SVM) strategy and methods that work with low switching frequencies, generally equal to frequency of the fundamental component and generate staircase waveform representatives are Space Vector Control (SVC), Minimization of the Total Harmonic Distortion (MTHD) [5].

Multilevel converters have some disadvantages, one is the need for a high number of power semi conductor switches. Although low voltage switches can be utilized, each switch requires a related gate driver and protection circuits. This may cause the overall system to be more expensive and complex[1]. Numerous topologies have been presented for

multilevel converters such as neutral point clamped (NPC) converter and cascade multicell converter (CM) [3]. For medium voltage applications the FCM converter, and its derivative, the SM converter are very interesting alternatives because of many advantages including transformer-less operation and self-balancing capability of flying capacitors that is achieved without feedback control [1]. The main feature of SM converter is to share the voltage constraint on several switches which reduces the voltage rating of the capacitors and semiconductor losses and increase the number of switching combinations to obtain the desired voltage level. The voltage natural balancing mechanism is a fundamental principle in flying capacitor and stacked multicell converts which consents to construction of voltage levels at the converter output[4].

In this paper a new control topology with Back-To-Back multicell converter with a few number of power electronic switches has introduced. This type of converter decrease the number of high frequency switches in comparison with the other converters, in addition to increase the number of output voltage levels. This control topology based on the sector modulation technique is presented. Comparison of the present control topology with the Phase Shifted Pulse Width Modulation (PSPWM) is presented. Finally the simulation results of the single phase 4-cell, 8-cell and 16-cell converters are illustrated to validate the back-to-back topology.

BACK-TO-BACK STACKED MULTICELL CONVERTER

This topology consists of two stacked multicell converters that are connected beck-to-back to each other by using two low frequency switches as indicated in figure 1.

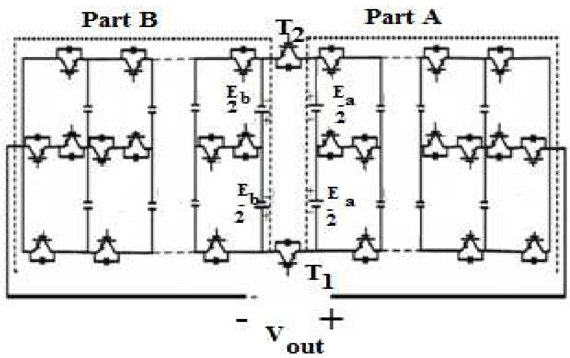

Figure 1: Back-To-Back Stacked Multicell Converter with 2(n+m) Cell

In order to investigate the advantages of this topology, a comparison between the back-to-back topology and CM, FCM and SMC converters are presented. This comparison considers the number of high frequency and low frequency switches, number of capacitors and dc voltage sources for the same number of output voltage levels. Combination of one dc source and two semi conductor switches connected back-to-back with the dc source. The number nodes to which the inverter can be accessible is known as a level. The number of switching combination to obtain the desired voltage level is increased and the number of voltage levels. Multicell multi converter system have been well known for many years for high voltage/high power applications to reduce the required blocking voltage of the power semi conductor device [2].

Table 1: Comparison of the BTBSMC Topology with Other Topologies for the Same Number of Output Voltage Levels

Type of Converter	Cascaded Multicell	Flying Capacitor Multicell	Stacked Multicell	Present Converter
No. of cells	N (N+4)/2	N (N+4)/2	N (N+4)/2	N
No. of high frequency switches	N (N+4)	N (N+4)	N (N+4)	2N
No. of low frequency switches	0	0	0	2
No. of capacitors	0	(N (N+4)/2)-1	(N (N+4)/2)-1	(N (N+4)/2)-1
No. of dc sources	N (N+4)/2	2	2	4

The concept of multilevel comes from acquiring a staircase output voltage waveform input dc voltages of appropriate converter configuration and its switching pattern properly. This multilevel voltage by its resemblance to sinusoidal voltage waveform leads to so many advantages of utilizing switches with low voltage ratings. Lower harmonic distortion, high power quality, etc, [4]. These two low frequency switches are used to obtain the positive and negative output levels. The polarity and the value of dc source applying used in the two parts are different.

Number of cells and output voltage can be calculated by using formulae below:

$$N_{cell} = 2(n+m) \tag{1}$$

$$N_{level} = 2[(2n+1)(2m+1)]-1 \tag{2}$$

Where E is the maximum output voltage. 2n and 2m are the numbers of cells which have been used in the part A and part B respectively [1].

The voltage values given to the dc sources

$$E_a = \frac{2n(2m+1)}{(2n+1)(2m+1)-1}E \tag{3}$$

$$E_b = E - E_a \tag{4}$$

For 4-cell converter the number of cells and levels are calculated as n=1 and m=1

$N_{cell} = 2(1+1) = 4$

$N_{level} = 2[(2+1)(2+1)]-1 = 17$

In this way if we required 8-cell and 16-cell then output voltage levels will be 49-lavel and 161-level respectively.

CONTROL TOPOLOGY

In the back-to-back stacked multicell converter, the arrangement of the switches and the dc voltage sources makes it possible to apply different control methods to generate the desired output voltage. One of the most common switching control is PSPWM method. In this method the switching pulses are generated by comparing the carrier signal to the reference signal. For the negative half cycle the reference waveform is shifted vertically (added by 1). Also, carrier waveform varies between 0.5 and 1 for the upper switches. As a result, the waveform generated by part A is symmetrical in the positive and negative half cycles[1].

In the proposed control method, the dc voltage is devided into sectors by using modulator sector calculation. There is no requirement of reference waveform shifting and adding as compared to PSPWM method. This is more advantageous and simple technique to generate pulses for higher number of levels.

The matrix converter provides importance benefits as sinusoidal input current with adjustable displacement angle. Bidirectional power flow, size reduction due to the reduction of dc-link capacitors [6]. The matrix converter has input modulator, MC modulator, output modulator and MC IGBTs switches[6].

Figure 3 Shows the sector identification and reference angle generation. The angle is generated from the reference output frequency by integrating it. The sector can be identified based on angle.

Sector selection (or) modulated degree selection is based on

$$N_{sectors} = 2(N_{levels)} + 2 \quad (5)$$

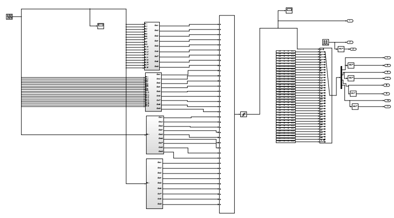

Figure 2: Control Technique

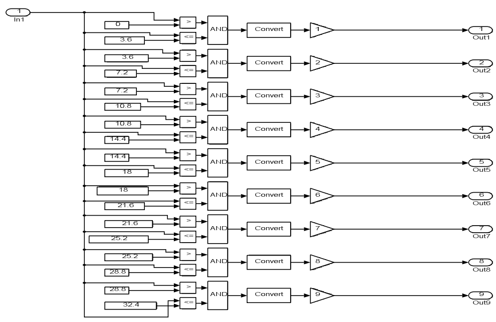

Figure 3: Sector Identification

$$\text{Each sector} = 360/N_{sectors} \text{ degrees} \quad (6)$$

After selection of degree we give that to multiport switch to select suitable switching state.

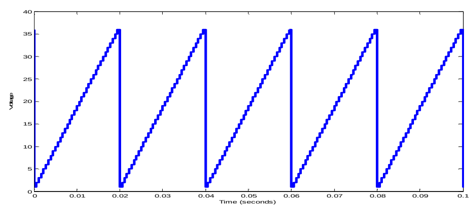

Figure 4: Control Signal for Multiport Switch

The switching pulses which are generated by using the control technique and will given to the switches. We can calculate the degree or sector modulation by using equations (5) and (6).

The switching states in Table 2 are also given to the multiport switch.

Table 2: Switching Table for 17-Level Converter

Output Voltage Levels	Conducting Schedule		
	T_1	T_2	(s_{11} s_{21} s_{12} s_{22})
+E	1	0	(1 1 1 1)
+7E/8	1	0	(1 1 1 0)
+6E/8	1	0	(1 1 0 0)
+5E/8	1	0	(0 1 1 1)
+4E/8	1	0	(0 1 0 1)
+3E/8	1	0	(0 1 0 0)
+2E/8	1	0	(0 0 1 1)
+1E/8	1	0	(0 0 0 1)
0	1	0	(0 0 0 0)
	1	0	(1 1 1 1)
-1E/8	1	0	(1 1 1 0)
-2E/8	0	1	(1 1 0 0)
-3E/8	0	1	(1 0 1 1)
-4E/8	0	1	(0 1 0 1)
-5E/8	0	1	(0 1 0 0)
-6E/8	0	1	(0 1 0 1)
-7E/8	0	1	(0 0 0 1)
-E	0	1	(0 0 0 0)

In the multiport switch the first input port is the control port and the other input are data ports. The switching states for 4-cell, 17-level are indicated in Table 2, as like that we have given the switching states for 8-cell and 16-level multilevel converters to obtain required sector identification. The modulated switching circuit is shown in Figure 5.

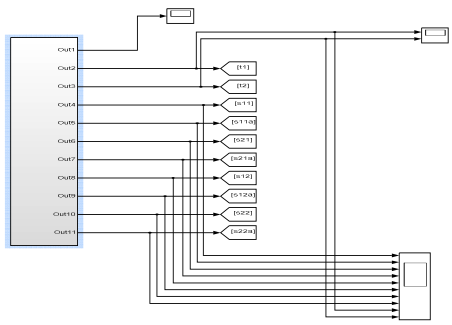

Figure 5: Modulated Switching Circuit

The obtained gate pulses are as shown in figure 5.

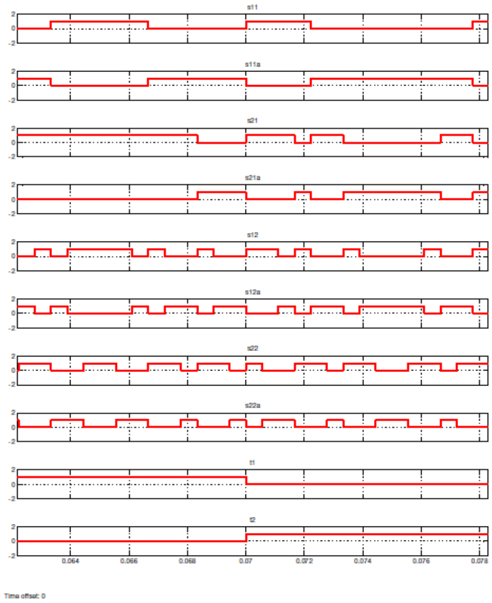

Figure 6: Generated Gate Pulses for 4-Cell

MATHEMATICAL ANALYSIS

When the number of cells are increasing then the number of output voltage levels also increasing. The converter with any number of level having only four voltage sources. When the number of output voltage sources are increasing then the number of switches and flying capacitors are increases. The main advantage of flying capacitor is that flying capacitor does not require a complex input transformer and number of dc sources and decreased[5]. For proper operation, the dc link voltage on each cell must accomplish with:

Capacitor Votage

$$V_c = \frac{iE}{2m} \tag{7}$$

For 2m cell

$$U_i = \frac{1}{2}C\left(\frac{iE}{2m}\right)^2 \tag{8}$$

Total energy stored

$$U_{TotalSM} = 2\sum_{i-1}^{m-1}\left(\frac{iE}{m}\right)^2 \tag{9}$$

$$U_{TotaSM} = C\left(\frac{E}{m}\right)^2\sum_{i-1}^{m-1}(i)^2 \tag{10}$$

SIMULATION MODEL

In this model IGBT switches are connected back-to-back and the gate pulses are given to the switches by using modulated sector control technique. Second order filters are used in this converter, which has high input impedance and

low output impedance and greater attenuation range. The simulation circuits are observed as follows

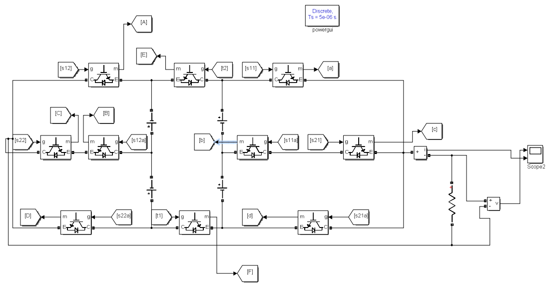

Figure 7: Simulink Diagram of 4-Cell, 17-Level Converter

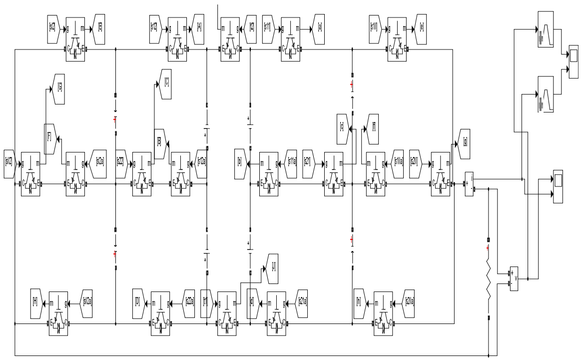

Figure 8: Simulink Diagram of 8-Cell, 49-Level Converter

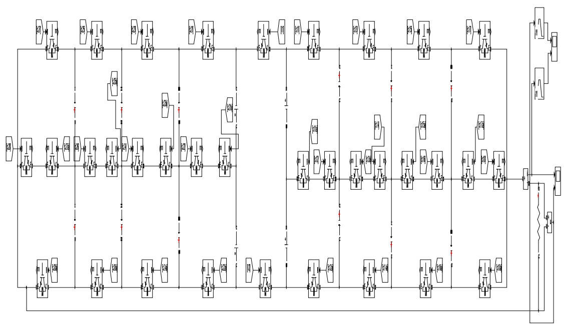

Figure 9: Simulink Diagram of 16-Cell, 161-Level Converter

SIMULATION RESULTS

The simulation circuits are simulated for the following test conditions and the results are observer as following

Test-I: The simulation circuit digram for 4-cell is simulated without using filter then the 17- level output is as shown in figure.10.

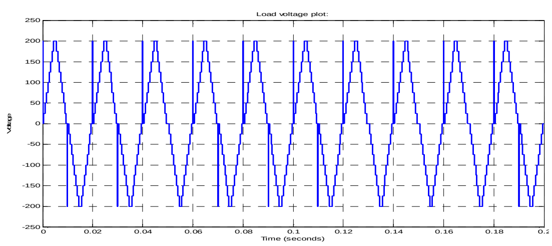

Figure 10: Outout Voltage Waveform for 17-Level Converter Without Filter

Test-II: The simulation circuit diagram for 4-cell is simulated with using filter then the output is observed as a sinusoidal wave form as shown in figure.11

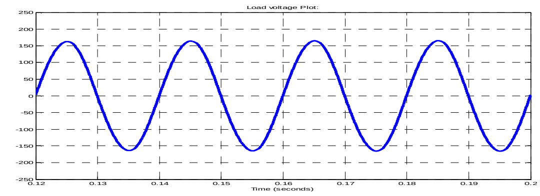

Figure 11: Output Voltage Waveform for 17-Level Converter with Filter

Test-III: The results for the 8-cell back-to-back stacked multicell converter without connecting filter are observed as 49-level output as shown in figure 12.

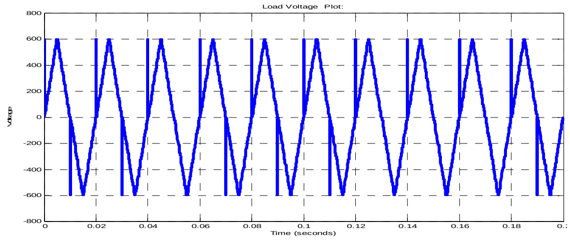

Figure 12: Output Voltage Waveform for 49-Level Converter Without Filter

Test-IV: The results for the 8-cell converter with filter are observed as sinusoidal waveform as shown in figure 13.

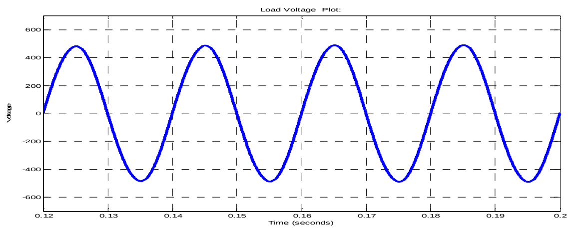

Figure 13: Output Voltage Waveform for 49-Level Converter with Filter

Test-V: The results for 16-cell converter without using filter are observed as 161 level output as shown in figure 14.

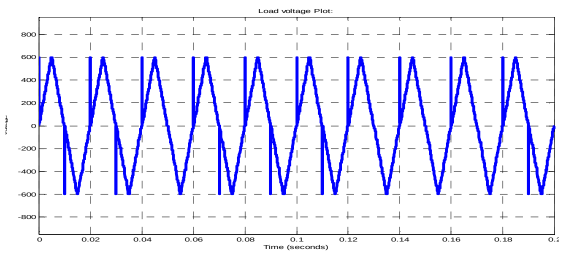

Figure 14: Output Voltage Waveform for 16-Cell Converter Without Filter

Test-VI: The results for 16-cell converter with using filter is observed as sinusoidal waveform as shown in figure 15.

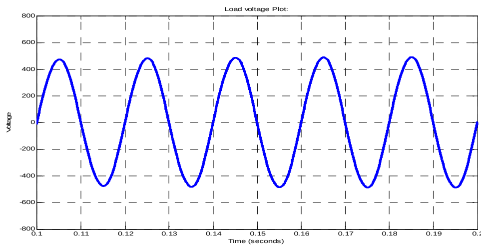

Figure 15: Output Voltage Waveform for 16-Cell Converter with Filter

HARMONIC ANALYSIS

To observe the power quality improvement of the obtaine voltage levels, Harmonic analysis is conducted by using powergui FFT analysis. Then the THD calculation results are observed as follows. By improving the number of cells then the percentage of THD is decreasing.

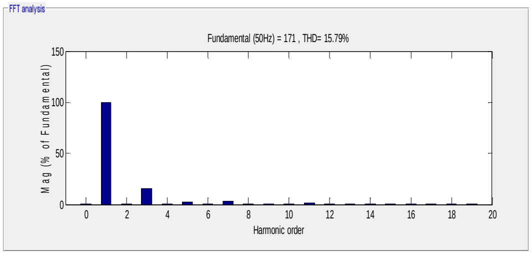

Figure 16: FFT Window of Output Voltage for 17-Level Converter Without Filter

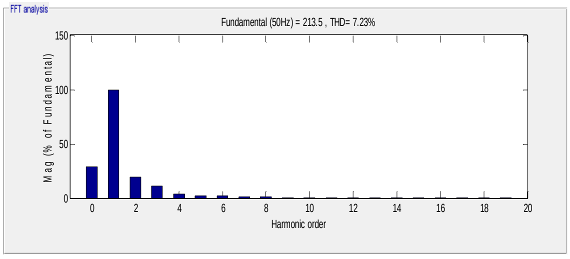

Figure 17: FFT Window of Output Voltage for 17-Level with Filter

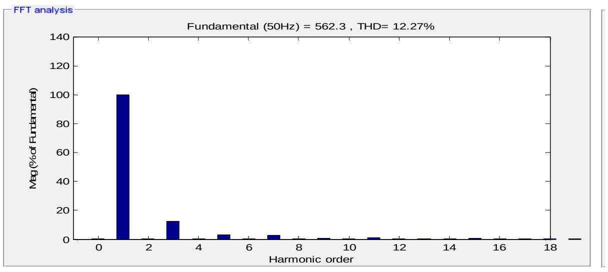

Figure 18: FFT Window of Output Voltage for 49- Level Without Filter

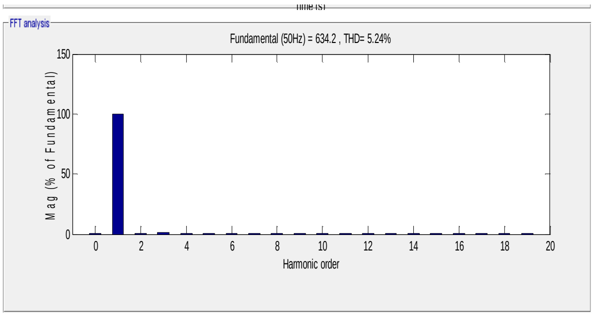

Figure 19: FFT Window of Output Voltage for 49-Level with Filter

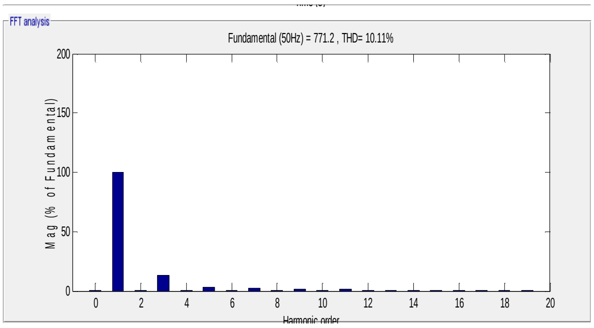

Figure 20: FFT Window of Output Voltage for 161-Level Without Filter

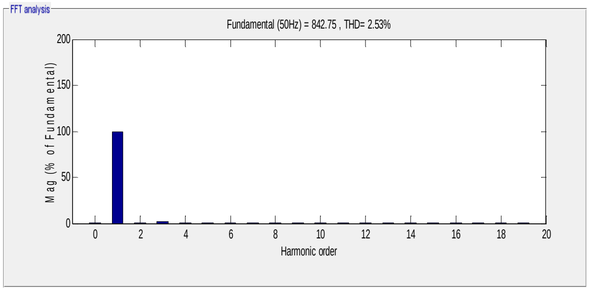

Figure 21: FFT Window of Output Voltage for 161-Level with Filter

As compared to other converters the proposed BTBSMC is advantageous. The number of capacitors in the proposed topology has a considerable reduction in comparison with the conventional topologies. This in turn leads to large reduction in the amount of stored energy [1].

Table 3: Comparison of Results

System Parameters	4-Cell	8-Cell	16-Cell
Level	17	49	161
No. of switches	4	8	16
Flying capacitors	0	4	4
Dc sources	4	4	4
E, E_a & E_b	200,150&50	600,500&100	800,720&80
Load resistance	10 ohms	10 ohms	10 ohms
THD% without filter	15.79%	12.27%	10.11%
Voltage magnitude at fundamental frequency	171V	562V	771.2V
THD% with filter	7.23%	5.24%	2.53%
Voltage magnitude at fundamental frequency	213.5V	634.2V	842.75V

This in turn leads to large reduction in the amount of stored energy[1]. The resullts are also compared both in case of using filter and also for without using filter. The voltage magnitudes are calculated at fundamental frequency as 50Hz.

CONCLUSONS

The back-to-back stacked multicell concept is used for a specific number of voltage levels, the proposed topology uses lower number of cells, lower number of capacitors and switches. As we seen in comparison of four eight and sixteen cell converters we can say that by improving the number of levels, we can decrease the harmonics and improve the power quality. There is a scope to use micro controller also to implement the switching at the data ports. These converters can be used in high power and high/medium voltage applications.

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